②

ARMY RESEARCH LABORATORY

Measurement Techniques for Electrothermal-Chemical Gun Diagnostics

G. L. Katulka
T. N. Khong
H. Burden
K. White

December 1993

ARL-TR-316

NOTICES

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 1993	Final, March 1992 - April 1993

4. TITLE AND SUBTITLE

Measurement Techniques for Electrothermal-Chemical Gun Diagnostics

5. FUNDING NUMBERS

PR: 1L162618AH80

6. AUTHOR(S)

G. L. Katulka, T. N. Khong, H. Burden, and K. White

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Research Laboratory
ATTN: AMSRL-WT-PA
Aberdeen Proving Ground, MD 21005-5066

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Research Laboratory
ATTN: AMSRL-OP-CI-B (Tech Lib)
Aberdeen Proving Ground, MD 21005-5066

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

ARL-TR-316

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Methods of acquiring data, including pressures, load current and voltage, and "crow-bar" diode current and voltage with a minimum of electrical noise in electrothermal-chemical (ETC) ballistic and combustion experiments are described. Measurements are performed in a 30-mm ETC gun facility that is driven by a 130-kJ (maximum) pulsed-power supply and a 50-cm^3 closed chamber facility using a 300-kJ power supply, both of which are located at the U.S. Army Research Laboratory. Strict attention is devoted to grounding of measurement and data-recording devices, as well as in shielding of measurement electronics, data lines, and high-power modulator components with "Faraday" enclosures. The use of ferrite rings on data lines and 60-Hz power lines is frequent, and fiber optical links are used for electrical isolation between data recording equipment and high-voltage components. The experimental arrangement and resulting data are presented, and comments and conclusions are included.

14. SUBJECT TERMS

voltage, data acquisition, electric noise, electrothermal-chemical, pulse forming network, pulse power supply, diagnostics (general)

15. NUMBER OF PAGES

35

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

INTENTIONALLY LEFT BLANK.

ACKNOWLEDGMENTS

The authors would like to thank the reviewers of this work, Mr. James DeSpirito, MAJ Kevin Nekula, Mr. Todd Rosenberger, and Mr. Alex Zielinski, for their extremely helpful suggestions and contributions.

INTENTIONALLY LEFT BLANK.

TABLE OF CONTENTS

INTENTIONALLY LEFT BLANK.

LIST OF FIGURES

INTENTIONALLY LEFT BLANK.

1. INTRODUCTION

Methods of acquiring experimental data including pressures, pulse forming network (PFN) currents, and voltages with a minimum of electrical noise that are critical to electrothermal-chemical (ETC) ballistic and combustion experiments are described. Measurements are performed in a 30-mm ETC gun facility that is driven by a 130-kJ (maximum) pulsed-power supply and a 50-cm^3 closed chamber facility using a 300-kJ power supply, both of which are located at the Army Research Laboratory (ARL), Aberdeen Proving Ground, MD. Strict attention is devoted to grounding of measurement and data-recording devices, as well as in shielding of measurement electronics, data lines, and high-power modulator components with "Faraday" enclosures.

Tests are performed that compare fiber-optic measurements with directly measured signals. A design of a third-order, low-pass filter is given, and its attenuation effect on high-frequency noise is demonstrated both analytically and experimentally. The use of ferrite rings on data lines and 60-Hz power lines is frequent and fiber optical links are used for electrical isolation between data recording equipment and high-voltage components. The experimental arrangements and resulting data are presented and a discussion of the data and conclusions are included.

2. BACKGROUND

The recording of experimental measurements in an ETC environment is complicated by the presence of a large, noise-producing source, namely, the PFN. The block diagram (Figure 1) can be used to compare fundamental differences in measurements made in an ETC environment to those made in a conventional ballistic diagnostic facility. The most significant difference between the two arrangements shown in Figure 1 is that of a high-energy PFN in an ETC gun facility. While the PFN is an essential source of electrical energy needed to initiate the combustion process of an ETC combustion event, it is also, unfortunately, the source of large amounts of electromagnetic radiation that can interfere with small signal experimental measurements. In fact, it has been reported in some ETC experiments the plasma generator itself causes electrical disturbances due to the violent electrical ignition of the fuse wire contained within the plasma capillary tube (Oberle 1993). As a result of these problems, much time has been devoted to the arrangement of the data acquisition systems of the ARL's ETC facilities, which are responsible for the measurement of experimental quantities. The following will provide a description of some of the measurement techniques that are used to help obtain reliable, noise-free experimental data.

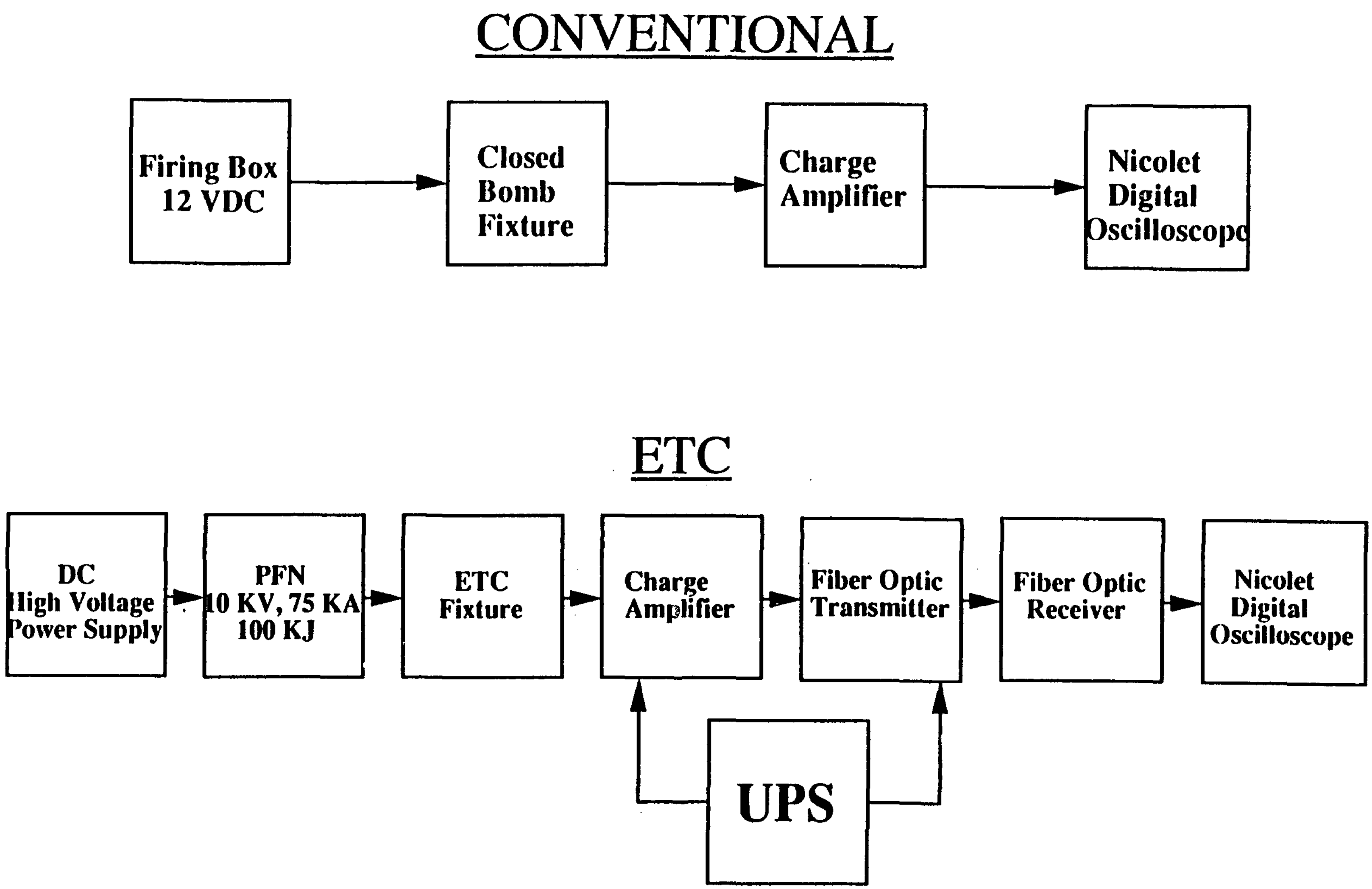


Figure 1. Comparison of ETC to conventional data acquisition systems.

3. PROCEDURE

The experimental arrangement employed in the 30-mm ETC facility, shown in Figure 2, consists of various data acquisition equipment, a grounding system, the electrical power supply (including the high-voltage DC charging supply and the PFN), an ETC diagnostic fixture, and a system of amplifiers and optoelectronics, which are used to transmit pressure measurement data. Nicolet digital oscilloscopes are used for the recording of experimental pressure, voltage, and current measurements, with the feature of digital data storage on 5.25-in floppy disks. As indicated in Figure 2, two separate locations are used for grounding of the oscilloscopes, and, to date, the resulting measurements in each case have provided very reliable experimental data in terms of immunity to electromagnetic interference (EMI) as in the experimental data taken by White et al. (1991). In systems such as this one, in which circuit impedances are measured in milliohms, a major noise-producing mechanism accompanying electromagnetic disturbances is the induction of current flow in measurement cable shields (Burden and Shear 1969). Because this requires a loop surrounding a changing magnetic field, a single point ground is a first requirement. The major system ground (labeled #2 in Figure 2)—actually the massive, heavily reinforced concrete gun mount which extended down 6 feet into moist ground—was accordingly defined. Thus, the oscilloscopes which attach directly to the discharge circuit are grounded only at this ground; isolating plugs are employed to prevent completion of the loop through the power line ground. (Such loops, in which the conductive ground forms part of the path, are called "ground loops.") The charge amplifiers and fiber optic transmitters are, perforce, grounded to the ETC chamber through the shields of the cables from the pressure gages mounted in its walls. While this is not precisely at the system ground, the chamber's outer walls have large conducting area and conduct no massive discharge currents and are thus electrically close to ground. The charges produced by these gages are measured in microcoulombs and the voltages derived are measured in millivolts; consequently, only very small noise voltages are permissible. To achieve these small values, two measures are taken. First, battery operation of the charge amplifiers and optical fiber transmitters is used, the batteries being provided by an uninterruptible power supply (UPS) unplugged from the AC line at shot time. Second, because the capacitance between any device and ground can complete a ground loop, double shielding—essentially Faraday shielding—is used around the signal cables and the electronic units.

Two other grounds are used. The first (labeled #1 in Figure 2) is undesirable but necessary for safety. It is the service ground to the high-voltage power supply as required by the National Electrical Code.

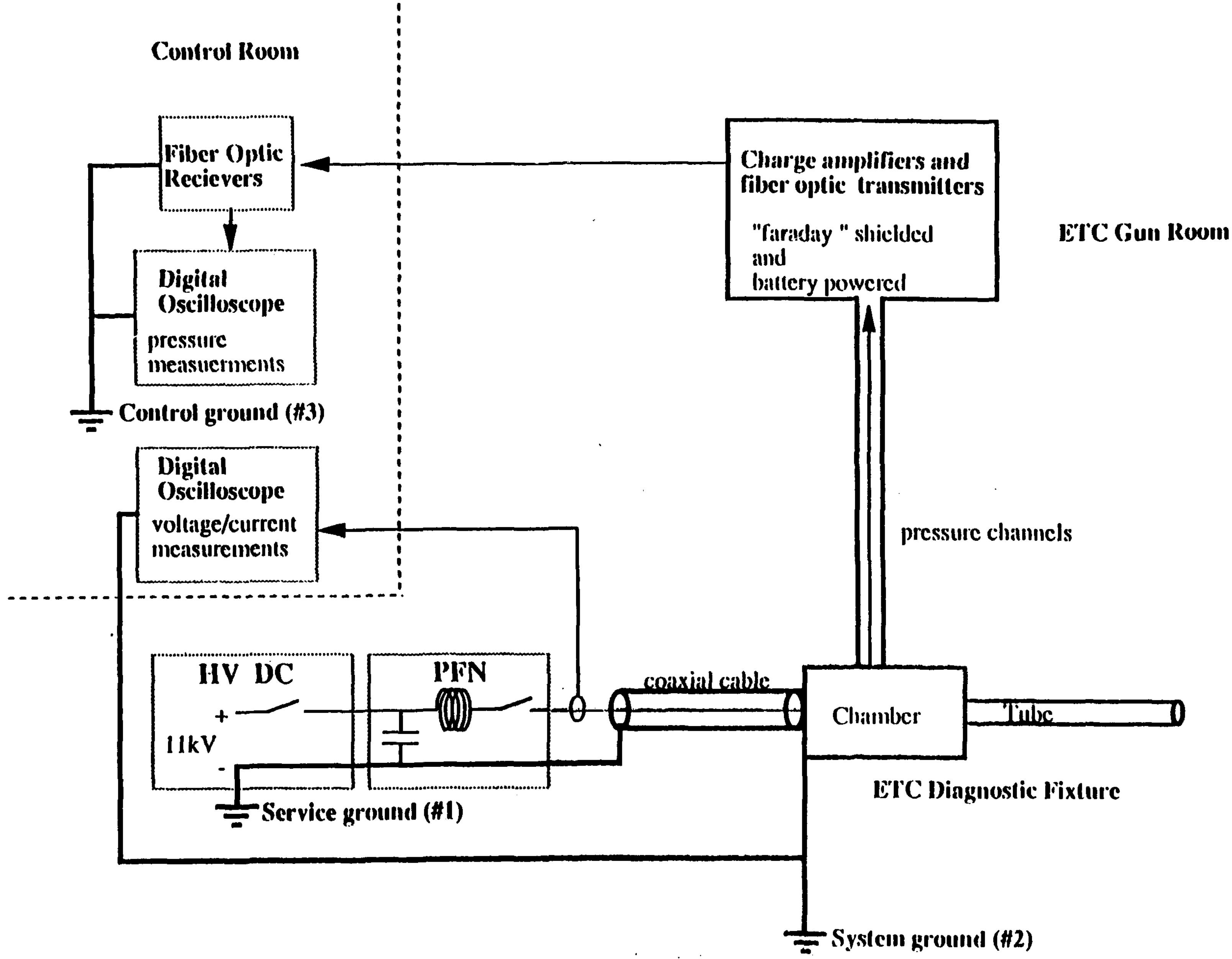


Figure 2. ETC gun diagnostics arrangement.

Because of its comparatively high inductance, it probably carries relatively little current from the discharge; also, the loop includes no signal circuitry so its effect is relatively unimportant. The second (labeled #3 in Figure 2) is the ground for the pressure measurement oscilloscopes. Since the output voltage levels from the optical fiber receivers are relatively high and the only loop of significance (the short link between optical fiber receiver and the oscilloscope) lies entirely in the recording room, a single earth ground, separate from the system ground and isolated from the AC service ground, was used here.

Kistler 607C piezoelectric pressure transducers were used for sensing chamber and gun tube pressures; experience at ARL confirmed the observation of personnel from GT Devices that those transducers containing internal signal conditioning electronics (voltage mode) are more susceptible to electrical noise than are straight (charge mode) piezoelectric transducers. Output from the transducers was converted by Kistler Model 5004 charge amplifiers to a voltage signal that can be recorded with digital oscilloscopes. Powell and Zielinski (1992) at the ARL successfully measured pressure between the anode and cathode of an ablating capillary discharge tube using essentially the same technique except that coupling to the oscilloscope was direct rather than optical.

3.1 Fiber-Optic Link Experiments. Frequency-modulated optical links (Dymec model numbers 6723/6722) are used to provide electrical isolation and are incorporated into each pressure measurement channel. The optical links have an analog bandwidth of DC to 1 MHz, which is more than adequate for the signals that are measured in this application (~50 kHz), and rely on frequency modulation of a 9-MHz carrier signal for data transmission. Because of the frequency modulation technique, the links are inherently less sensitive to attenuation and losses due to optical connectors or other perturbations in the optical fiber. Operational issues that are relevant to this particular application of these optical fiber links have been addressed by Fortier et al. (1992) at the ARL. As indicated in Figure 2, the optical transmitters and the charge amplifiers are located in the interior of a "Faraday," or shielding box, which is used to protect the equipment from electric fields. Each individual piece of equipment inside the Faraday box is physically separated with nonconductive material from the other equipment and the structure of the box itself. Also, each piece of equipment had its electrical power (110 V, 60 Hz) supplied by a single 750-VA UPS. The thought behind the three elements of EMI shielding, single point grounding and the use of a UPS, as previously discussed, is to prohibit the generation of EMI noise and to prevent ground loops or paths which aid in the flow of noise current through grounded wires of data signal paths (Burden and Shear 1969).

The susceptibility of the fiber-optic link to electrical noise has been experimentally tested at the ARL in the 130-kJ/30-mm ETC Diagnostics Laboratory. The purpose of the following test was to determine what grounding and power-source configurations for an optically coupled data acquisition are most successful in terms of acquiring noise-free electrical data. This is done by making comparisons of direct measurements with optically coupled measurements, the latter of which are sensitive to grounding and power supply noise due to the added complexities of their receiver and transmitter electronics. Since, under normal operating circumstances, it is required to make these measurements in the harsh EMI environment of a discharging power supply, this experiment consisted of making measurements during the discharge of the 130-kJ PFN into a fixed 35-milliohm resistive load. The PFN was discharged three times with a different data acquisition arrangement each time (i.e., different primary power and EMI shielding arrangement). During the discharges, measurements were made of the time rate of change of the load current (di/dt) via a Rogowski coil. A current waveform is obtained by performing a numerical integration on the resulting di/dt waveform. The accuracy of the current waveform is dependent upon the di/dt waveform; therefore, it is essential to make extremely accurate di/dt measurements. The output from the Rogowski coil was coupled, in parallel, to separate digital oscilloscopes for each of the three discharges. One measurement is made directly with a Nicolet model 4094 digital oscilloscope while another is optically coupled via a frequency modulated, Dymec fiber- optical system as previously described. A 100-m length of fiber-optic cable was used to connect the optical transmitter with the receiver. With the experimental setup as just described, a comparison between the direct measurements and optically coupled measurements was made. To rule out inconsistencies in noise levels in the laboratory during the test, the initial stored energy level of each discharge is kept constant at 10 kJ.

The setup of equipment in the first discharge is shown in Figure 3. The optical transmitter is placed physically close to the PFN (approximately 0.5 m away from output connection), and it is powered by a 110-V AC receptacle outlet. The receiver is also powered by an outlet; however, the grounding prong on the receiver unit is intentionally disconnected with the use of an adapter plug. The receiver output is terminated at the input of the second 4094 Nicolet oscilloscope, which also has an adapter plug disconnecting the grounding wire. The resulting measurement of di/dt (Figure 4a) as recorded directly with an oscilloscope, was free from noise; consequently, the integrated waveform produced a noise-free load current trace. On the other hand, the measurement obtained with the fiber-optic link (Figure 4b) was very badly distorted, and it does not least resemble the true waveform.

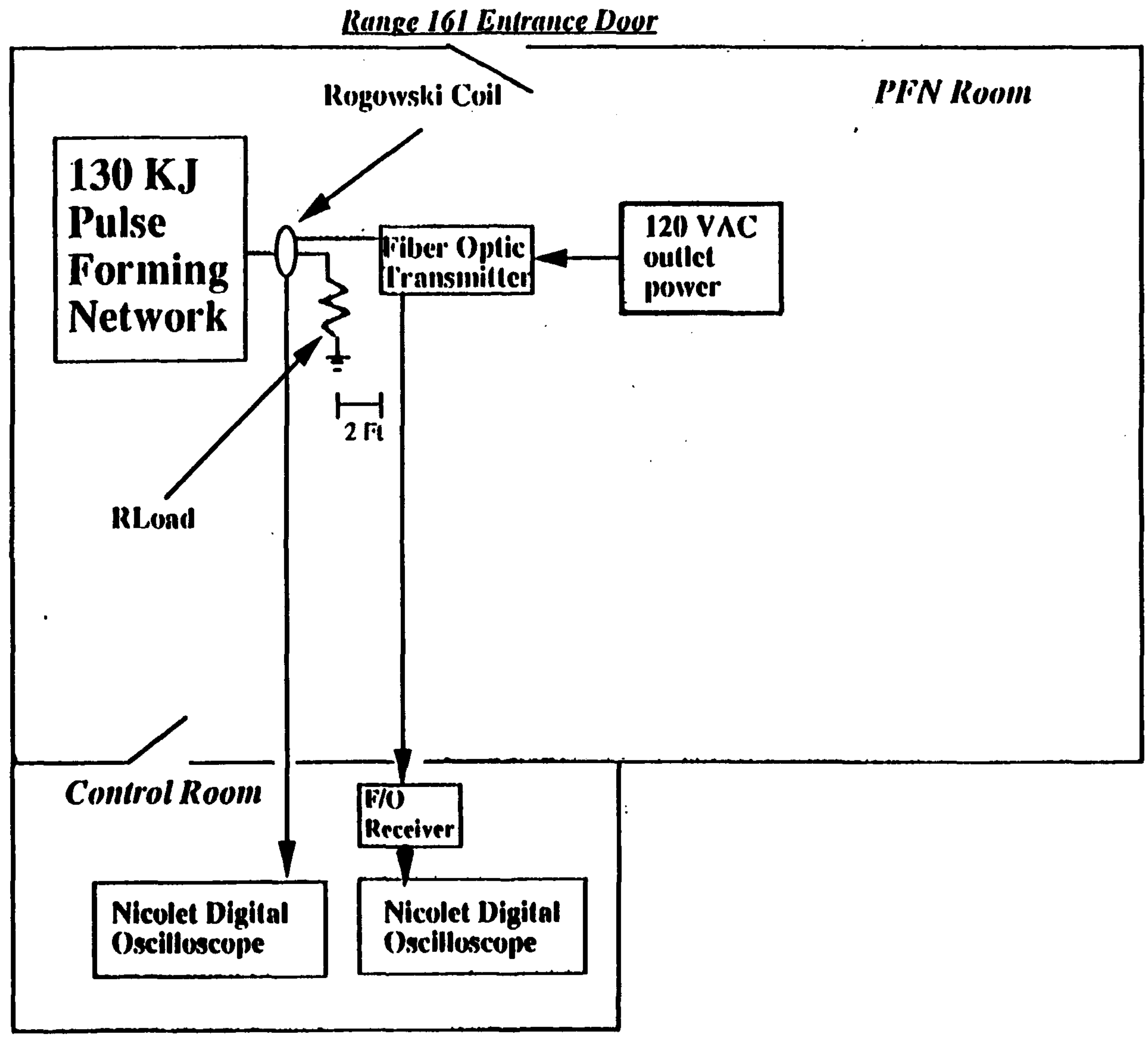
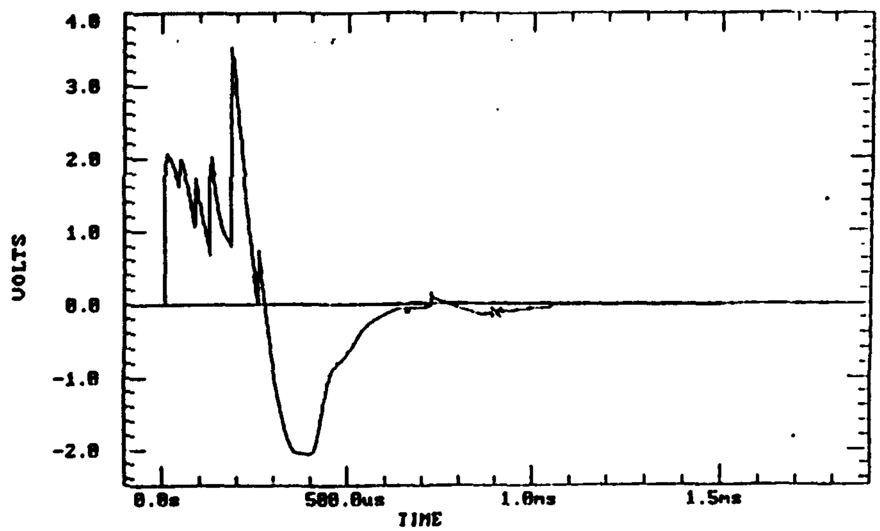
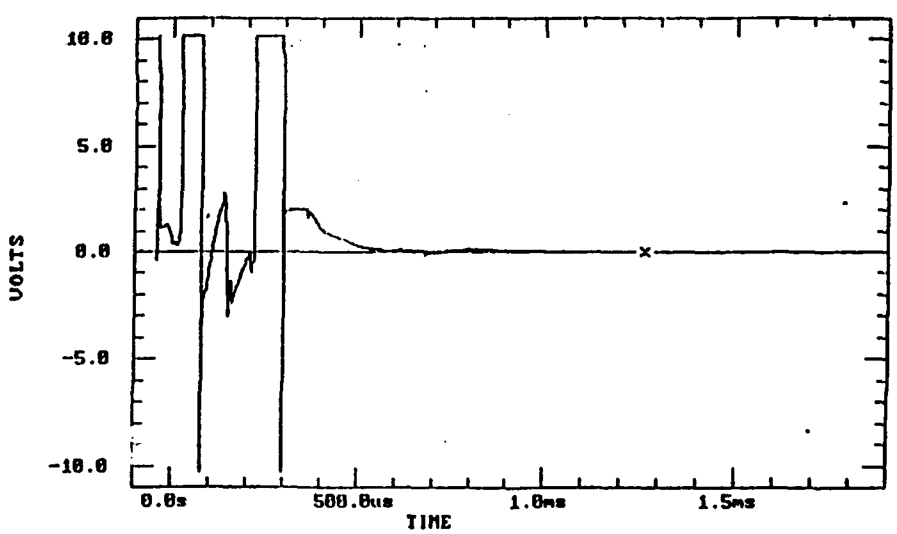


Figure 3. Pressure measurements with oscilloscope grounded at control room ground.



(a) Direct



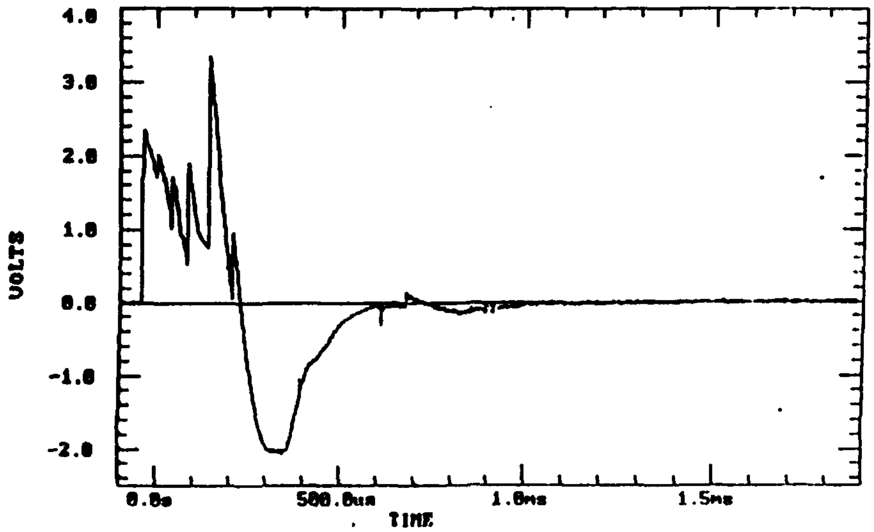
(b) Optical

Figure 4. Load di/dt waveforms for the first discharge, (a) direct and (b) optically coupled.

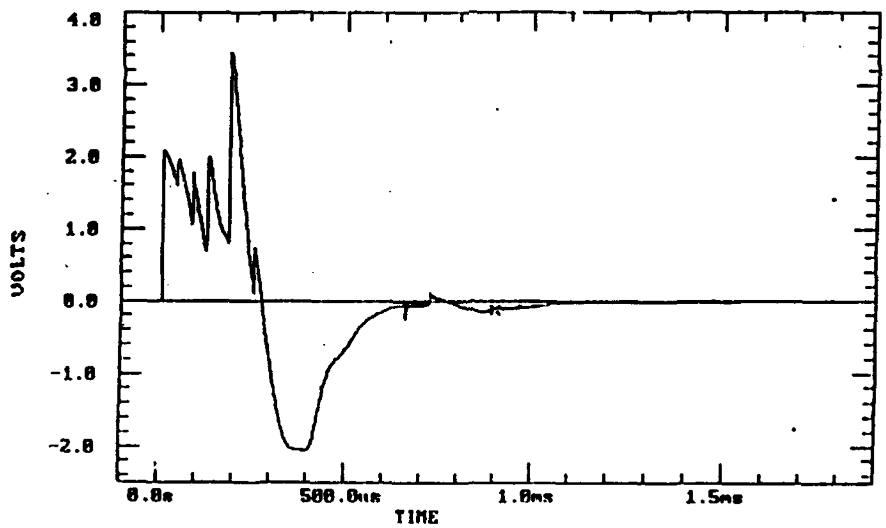
For the second discharge, the fiber-optic transmitter was powered by a UPS. The UPS was disconnected from the utility power system; therefore, it is supplying the transmitter from a converted DC battery supply, which is completely electrically isolated from the utility network. The location of the UPS is in the interior of an ungrounded, metal Faraday enclosure that was located 2 m away from the nearest current-carrying component (prepulse bank ignitron) of the PFN. The UPS is electrically isolated from all parts of the metal enclosure and a household grade extension cord, running parallel to the PFN, is used to connect the UPS to the optical transmitter. This arrangement of the transmitter and UPS is such that all equipment on the measurement, or transmitting side, is ungrounded or left "floating" from the PFN and utility grounds. The AC cord of the UPS is external to the Faraday enclosure, and the fiber-optic receiver and oscilloscope are set up identically as in the first discharge. In this case, the resulting measurements (Figure 5) from both arrangements are free of noise, and, in fact, they are nearly identical when compared directly.

For the third and final primary power arrangement, the experiment was unchanged with the exception of the removal of the UPS from the enclosure to a location just 0.5 m from the PFN load/output connection. The results from this configuration were very similar to the data obtained in the second configuration thus indicating that the power source isolation proved by a UPS or similar unit is highly useful in minimizing electrical noise in data systems. As is illustrated by our efforts with the very sensitive charge amplifiers, the degree to which such means alone are useful will depend upon the circuit arrangements, the relative noise and signal levels, and the sensitivity of the equipment involved. Figure 6 shows a plot of the optical measurement values subtracted from the direct measurement values. Dividing this result by the value of the direct measurement and multiplying by 100 yields the percent error between the two approaches, as illustrated in Figure 7. More will be said about the error in the optical measurement in the discussion section of this report.

3.2 Filter Design Experiment. A transient noise problem associated with the UPS was observed during similar tests. Amplitude peaks or "spikes" in line voltage were introduced into the pressure channels (see Figure 8) by the switching circuitry of the UPS. Figure 8 shows the response of a pressure transducer mounted in the chamber of an unpressurized ETC fixture. The arrangement for this pressure channel is as shown in Figure 2. The UPS was in the battery powered mode, and it is supplying inverted AC power to the charge amplifier and the optical transmitter. It was noticed that with only the UPS operating, transient voltage waveforms with peak amplitudes of about 100 mV are introduced into the pressure channel. Because the transient noise repeats with a 16.7-ms period it is almost certainly a result



(a) Measured di/dt (direct)



(b) Measured di/dt (optical)

Figure 5. Load di/dt waveform for second discharge, (a) direct and (b) optically coupled.

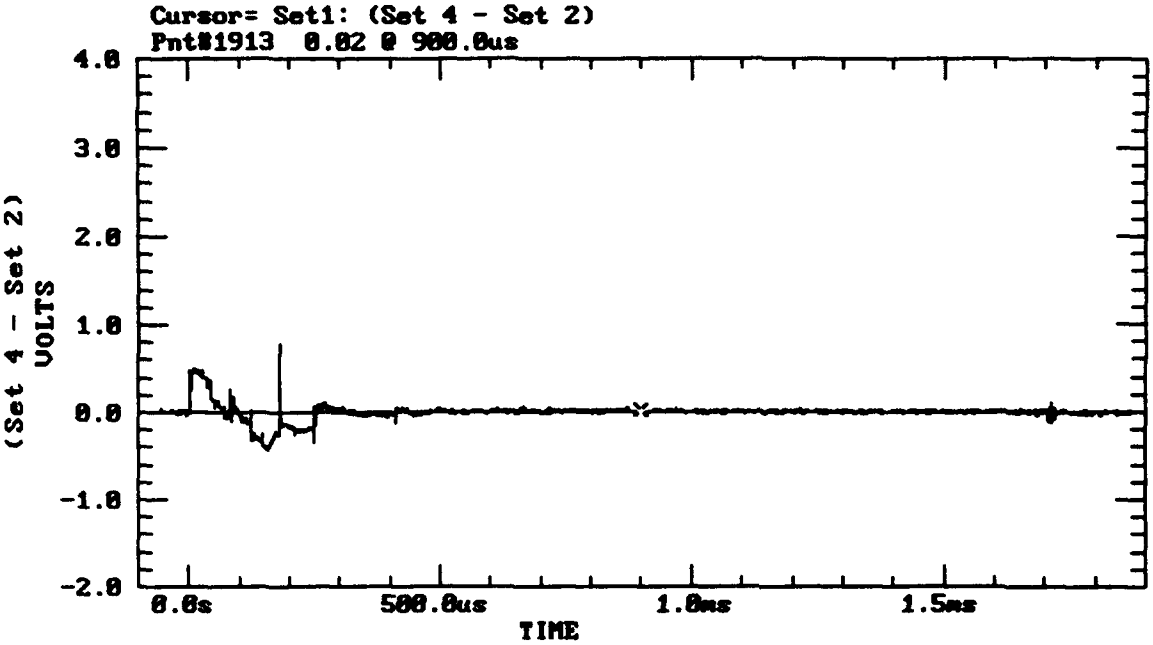


Figure 6. Optically coupled waveform subtracted from direct coupled waveform.

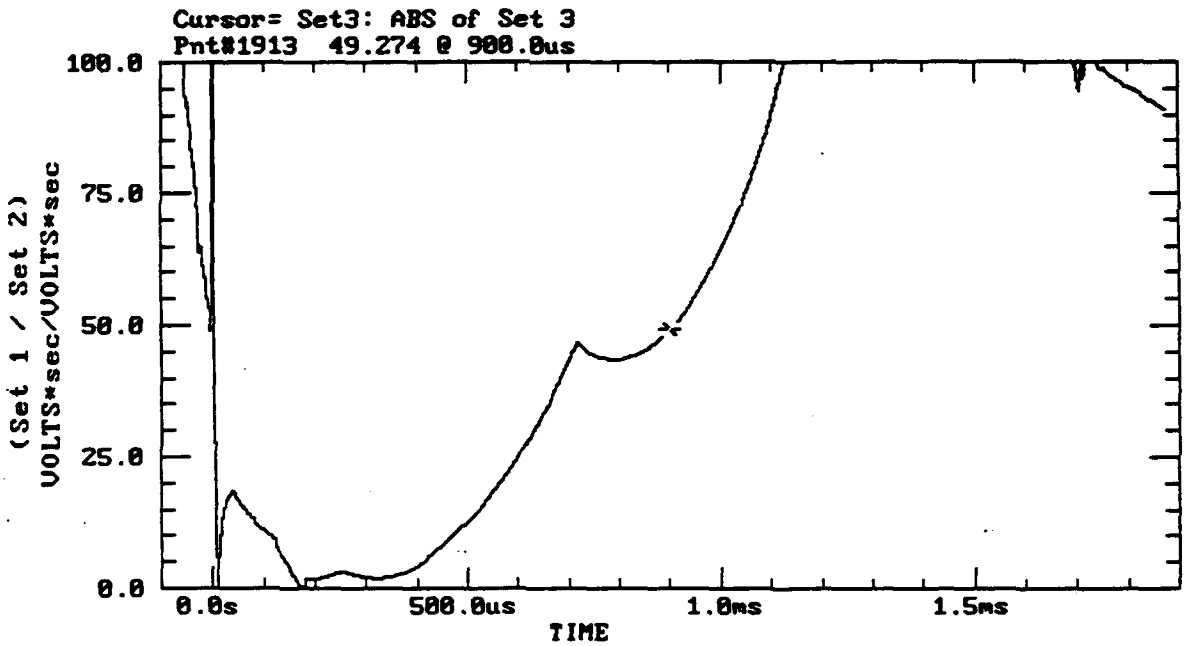


Figure 7. Percent difference of optically coupled and direct coupled waveforms.

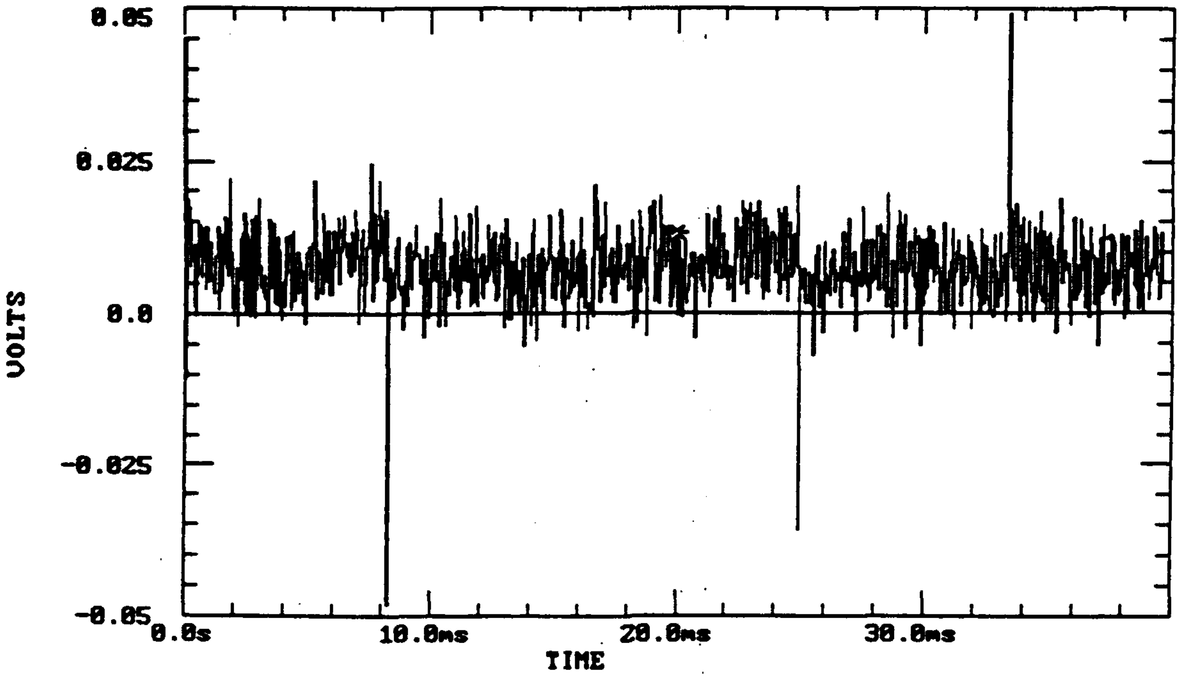


Figure 8. Pressure channel response with transient noise interference.

of the conversion process in the 60-Herz UPS power source. Further, because the UPS inverter completes a positive and a negative excursion in each cycle, positive as well as negative transients should occur during the 16 ms; this too is evident in the waveform of Figure 8, except that a positive 500-mV spike expected at 16 ms on the plot is missing. This was lost by the oscilloscope because its digital sampling rate was not high enough to capture all the transient portions of the waveform in this particular time window.

One solution to this problem was in the design and implementation of a third-order, low-pass filter with a cutoff frequency of 7.5 kHz. A low-pass filter of this type will allow 60 Hz to pass unattenuated, but it will filter the power supply of noise above the 7.5 kHz cut off (note the 40 kHz transient noise is well above the 7.5 kHz cut off). The diagram of the filter is given in Figure 9. The Laplace transform technique is used to obtain the transfer function of the output voltage with respect to the input voltage

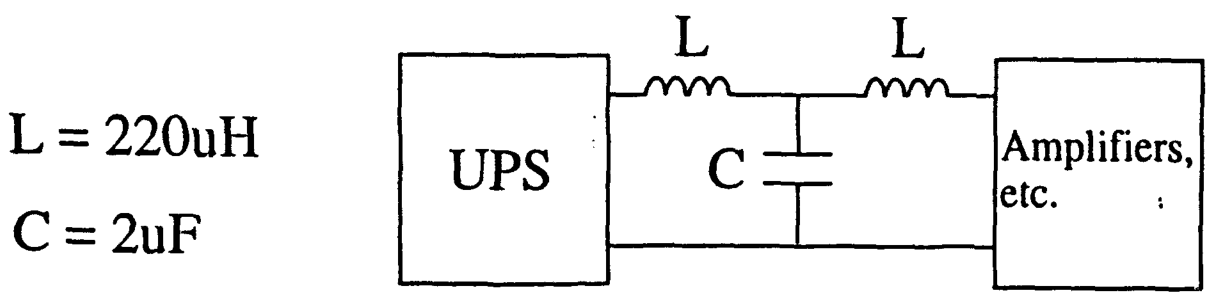


Figure 9. Third-order low-pass circuit diagram.

of the filter ($V_2(S)/V_1(S)$). This is accomplished by replacing all inductance terms (L) with their corresponding Laplace transform (LS) (Hostetter 1984). The same is done for the capacitances, voltages, and currents in the circuit. Now the transfer function can be solved for by simple algebraic techniques, as shown. Using Kirkoff's Voltage Law on the two circuit loops yields the following two equations:

$$V_1(S) = I_1(S)LS + (1/CS)\left(I_1(S) - I_2(S)\right); \tag{1}$$

$$V_2(S) = -(1/CS)\left(I_2(S) - I_1(S)\right) - I_2(S)LS. \tag{2}$$

In addition,

$$V_2(S) = I_2(S)R. \tag{3}$$

Solving for $I_1(S)$ in Equation 1 and substituting into Equation 2 gives

$$V_2(S) = -(1/CS)(I_2(S) - (V_1(S) + I_2(S)/CS)/(LS + 1/CS)) - I_2(S)LS. \tag{4}$$

Substituting $I_2(S)R$ for $V_2(S)$ into Equation 4 and rearranging yields

$$I_2(S)/V_1(S) = 1/(L^2CS^3 + RLCS^2 + 2LS + R). \tag{5}$$

Finally, multiplying both sides of Equation 5 by R yields

$$V_2(S)/V_1(S) = R/(L^2CS^3 + RLS^2 + 2LS + R). \qquad (6)$$

Equation 6 is the third-order transfer function of the filter that is shown in Figure 9.

The values of L = 220 μH and C = 2.0 μf were chosen to give a cutoff frequency at about 7.5 kHz, based on a load R = 480 ohms (the total impedance of the fiber-optic transmitters). These values give a cutoff which is well below the frequency of the transient noise. The resulting gain vs. frequency plot (Bode plot) for this transfer function is shown in Figure 10. By introducing this to output of the UPS, the noise was completely eliminated from the 60-Hz UPS power supply and from the pressure channel trace. Based on the results of this particular test, it is suggested to correct for this problem if any electronics equipment in the data acquisition system is powered by a similar UPS.

3.3 Common Mode Rejector. A technique using rings of ferromagnetic material to attenuate the amplitude of noise currents that flow in the shield or grounded conductors of any electrical equipment in the data acquisition system is used. The technique employs a device known as a "common mode rejector" and it is used to attenuate or reject signals traveling in the ground or common conductors of a circuit (Askeland 1985). This technique has been successfully applied to other experimental work including the pressure measurements made in the Electromagnetic Railgun Laboratory of the ARL (Powell and Zielinski 1992). The ferromagnetic rings, or "ferrites," contain iron oxides, and they generally have a high relative permeability. This characteristic of high permeability enables the ferrite to introduce an amplification effect of the magnetic field (or inductance) generated by current-carrying conductors surrounding the material. Common ferrites include $NiFe_2O_4$, $MnFe_2O_4$, and $(Zn,Mn)Fe_2O_4$ (Askeland 1985).

Ferrites are implemented by wrapping the power cords and coaxial data lines of all electronics equipment tightly for several turns around the ferrite material. Figure 11 shows the circuit diagrams of the resulting arrangement, with the addition of a ferrite. The circuit includes a voltage source, the series resistance of the data lines (Rs), the inductances due to the windings around the ferrite, and the load voltage measurement. By examining the circuit closely, it can be seen that for the current flowing from the voltage source, the associated magnetic fields in the ferrite will be equal in magnitude and opposite

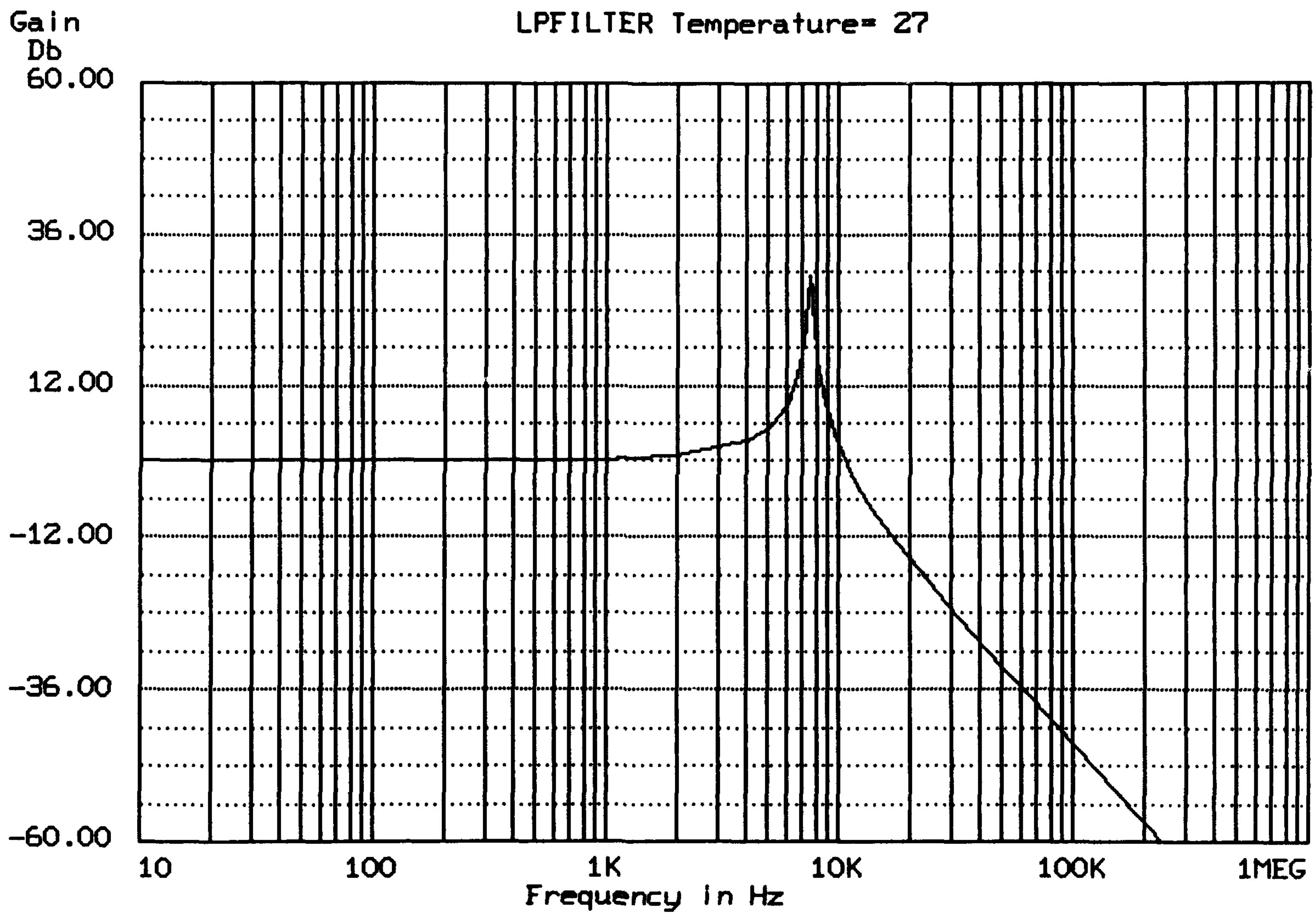


Figure 10. Magnitude vs. frequency plot for low-pass filter used.

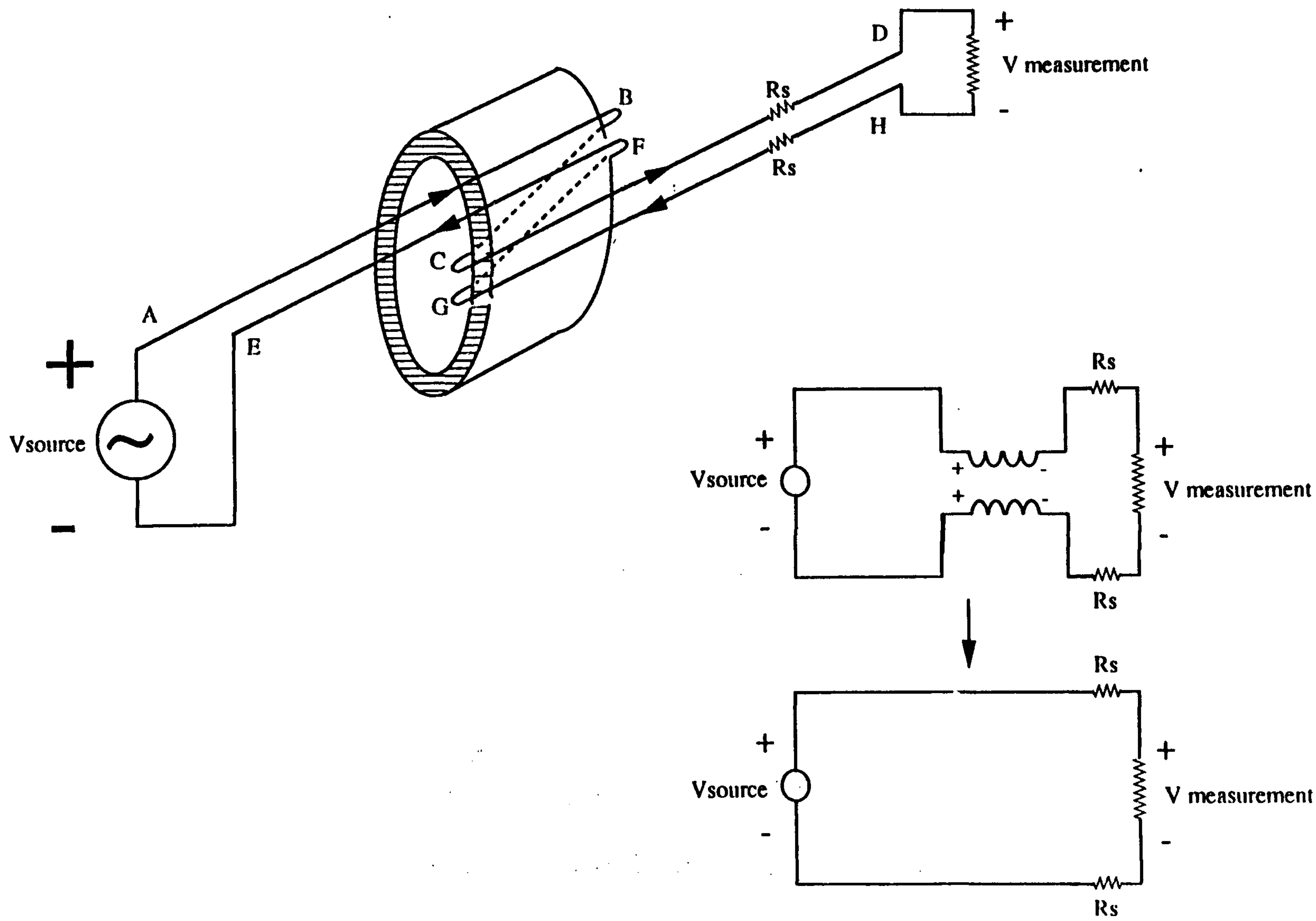


Figure 11. Equivalent circuits for common mode rejector.

in direction and will, therefore, cancel each other. As a result to the current that flows in this data signal loop, the effect of the ferrite is negligible. However, any current traveling unidirectionally with respect to the ferrite (typical of noise current from a ground loop, see Figure 12) will generate net magnetic field (inductance) through the ferrite. Consider the equivalent circuit shown in Figure 12. V_{noise} may be generated by the inductive loop made up of the ground path and the leads connecting V_{source} to $V_{measurement}$. Depending on the source and measurement impedances, a V_{noise} signal will be developed across one of the Rs resistances that may not be canceled by the signal developed across the other Rs. This then will show up in $V_{measurement}$. However, with the presence of the inductive impedance (reactance) given by the ferrite core, this will be in series with Rs and is shown in the equivalent circuit in Figure 12. The addition of the inductance generated in this path will, like the addition of impedance to any circuit path, have a tendency to decrease the current amplitude and hence the V_{noise} developed across Rs (see Figure 11). Although this is a desirable situation if a ground loop is introduced into the measurement system, its effectiveness is limited by the frequency of the noise current. This is because the impedance introduced by the ferrite is proportional to the product of frequency and inductance, given by

$$XL = jwL = 2*\pi*f*L. \tag{7}$$

In Equation 7, f is the frequency of the applied signal in Hz, L is the inductance in henrys (H), and π is a constant given as 3.14159. As an example, the impedance offered by a typical inductance at 100 kHz can be as much as 1,256 ohms, which will have a pronounced effect on current traveling in a ground loop having an impedance of fractions of an ohm (typically, Rs = 0.1 ohm). However, the same inductance will produce only 12.56 ohms of impedance for the same current at 1 kHz. Even so, the attenuation effect of a common mode rejecter on lower frequency signals can be seen experimentally. Figure 13 shows the result of noise coupled into a pressure channel (in the absence of pressure) during a PFN discharge into the 35-milliohm resistive load. The difference between the two arrangements is that in 13b the pressure channel circuit contains a 20-turn ferrite whereas the circuit of 13a has no ferrite. It is seen from Figure 13 that the frequency of the unwanted noise pickup is on the order of 1–2 kHz, possibly due to the magnetic field pick up from the discharging PFN which is on the order of 0.5 to 1 ms. As described above, this frequency pickup can be effectively reduced by the ferrite common mode rejector.

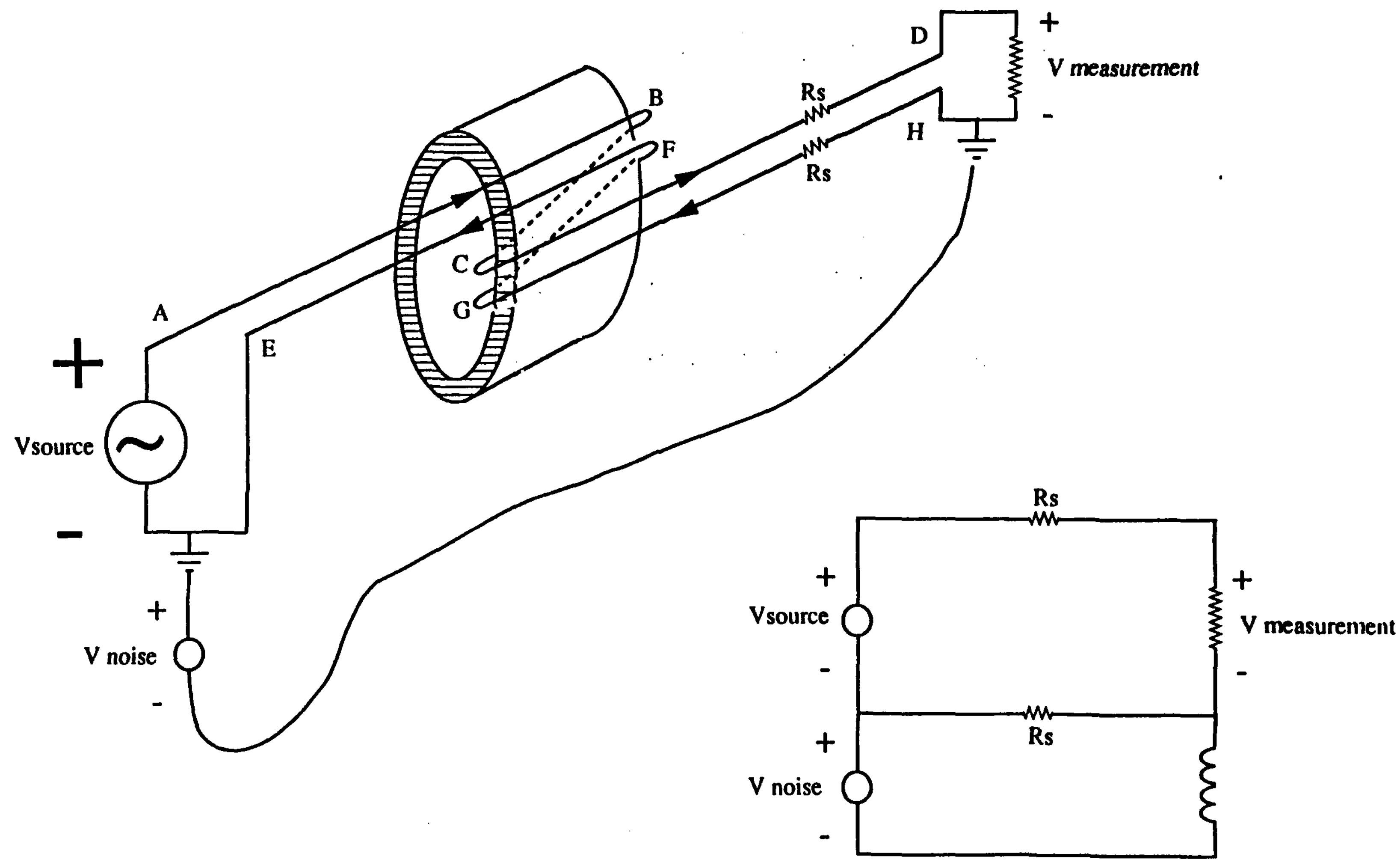
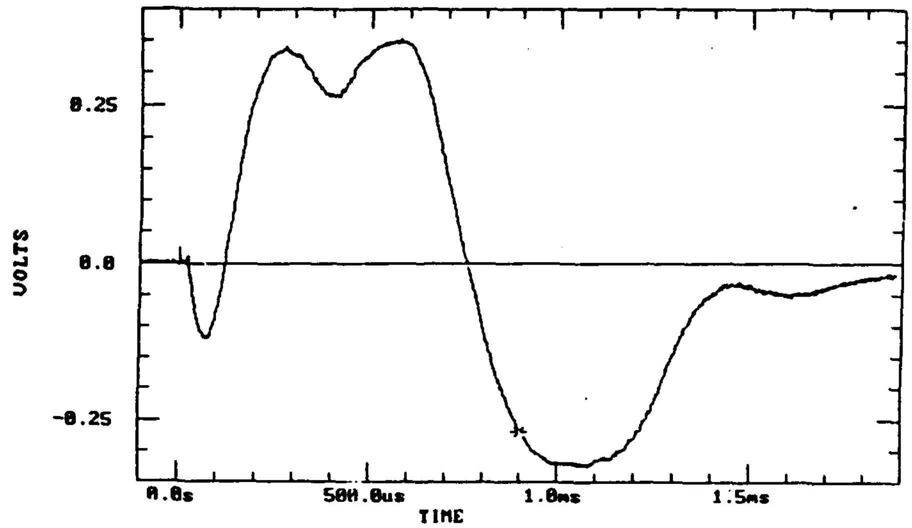
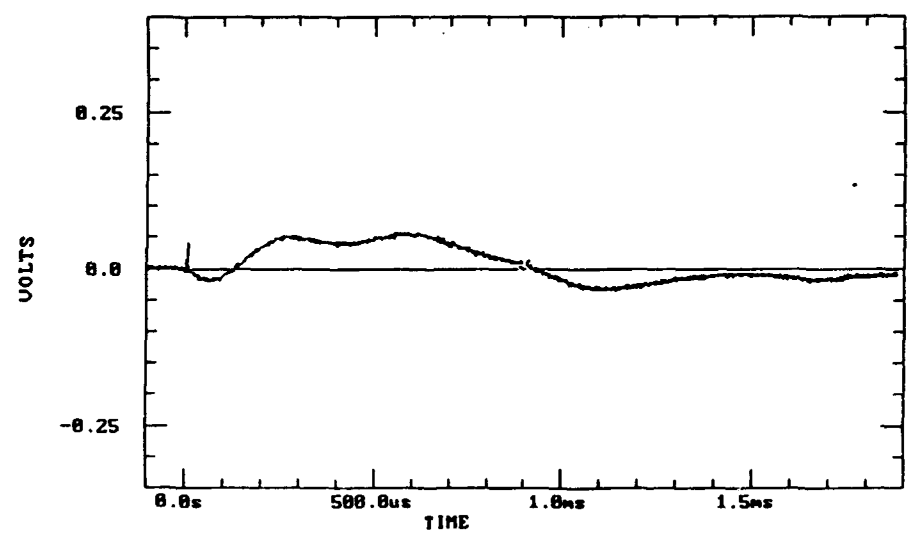


Figure 12. Equivalent circuits for rejector used in a circuit having a ground loop.



a) Without rejector



b) With 20-turn rejector

Figure 13. Response of pressure channel, (a) without rejector (b) with addition of rejector.

4. DISCUSSION

The percent error calculation shown in Figure 7 reveals very large errors in areas where the functions are near to zero and reasonable error (< 5%) elsewhere. The large error observed in areas of small signal magnitude is due to the signal-to-noise (S/N) ratio of the optical links. In support of this claim, Figure 14 shows the optical and direct measurements from the third discharge, discussed earlier, with an expanded vertical scale. The figure illustrates the large difference and, consequently, large percent error between the two functions in regions of relatively low signal levels. The large difference between the two signals is due to background noise introduced by the optically coupled signal. In Figure 14, for example, the data point on the direct signal (solid line) at 950 μs is about –0.05 V, compared to –0.02 for the optical signal (dotted line) giving a percentage difference of 60%. Again, this large difference is caused from noise introduced into the fiber-optic measurement due to the very low S/N in this region. In fact, the manufacturer of the fiber-optic links clearly state the minimum S/N as 40 db. For the data points 950 μs, the calculated S/N ratio is 3.98 db or about one tenth the minimum value required by the manufacturer.

On the other hand, for larger signals (see Figure 14), the S/N ratio is larger and thus the agreement between the two functions is much improved. It is important to mention that the peak current values obtained from the numerical integration of the signals have very good agreement. In fact, the comparison of peak current values obtained from the two signals (direct and optically coupled) reveals a relatively small percent difference of 2.7%. In addition, the percent difference of the calculated energy obtained from the integral of the current squared multiplied by the load resistance for each signal is only 3.2%, again quite good.

Reasoning as to why good agreement is obtained for overall energy and peak current measurements can be deduced from current and energy profiles in addition to Figures 7 and 14. The energy and current traces for this PFN discharge indicate that most of the current and energy are delivered to the load up to approximately 500 μs in time; this is the region of very good agreement between the two signals as seen in either of the two figures as stated. As a result, one would expect a small percent difference between the two values since there are relatively small discrepancies between the di/dt signals obtained.

Some of the error between the two peak currents and calculated energy may be introduced from the numerical integration program, although this is, in most cases, probably quite small as long as the

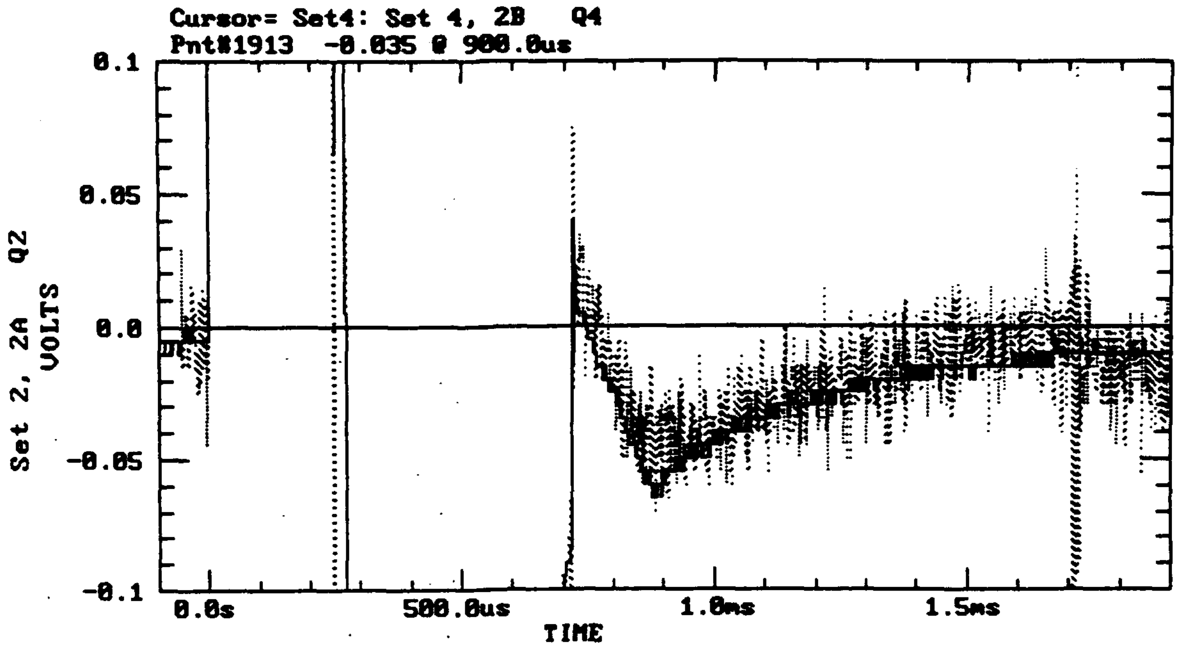


Figure 14. Common mode rejector with circuit having a ground loop.

digitization period of these signals is small compared to the integration window. In summary, as long as the measured signals meet the required S/N ratio plus any obvious specifications of the fiber-optic links, the resulting measurements can be expected to be within about 3% of the accuracy of signals obtained through direct or passive techniques.

5. CONCLUSIONS

A data acquisition system that has allowed for reliable, noise-free experimental measurements in the ETC diagnostic environment at the ARL has been designed and experimentally tested to provide reliable measurements. This includes a system of shielded pressure channels, optoelectronic equipment, a UPS, digital oscilloscopes, and a multi-point grounding system. Tests have been performed to determine a sound arrangement for grounding and for supplying power to a particular type of optoelectronic and amplifier equipment.

It has been determined that the optical equipment provided data to within 3% accuracy of directly acquired data of current and energy delivered to a resistive load. Also, a filter design has been offered for the elimination of voltage "spikes" that are introduced by the switching elements of a UPS. Finally, a technique involving common mode rejectors (ferrites) used to attenuate ground loop currents has been described and experimental data showing its effectiveness were put forward.

INTENTIONALLY LEFT BLANK.

6. REFERENCES

Askeland, D. R. The Science and Engineering of Materials. Prindle, Weber, and Schmidt, 1985.

Burden, H. S., and D. D. Shear. "Transient Noise in Electronic Measurements." BRL Report 1442, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1969.

Fortier, S., A. Juhasz, M. DelGuercio, K. White, and G. Katulka. "Combustion Characterization Comparison Plasma Augmented ETC Solid Propellants." BRL Technical Report in Publication, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, September 1992.

Hostetter, G. H. Engineering Network Analysis. New York: Harper and Row, 1984.

Matthew, J. "Common-Mode Rejecters For Pulse Power Diagnostics." Memorandum Report 6607, U.S. Naval Research Laboratory, 15 February 1990.

Oberle, W. F. Private communications. U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, February 1993.

Powell, J. D., and A. E. Zielinski. "Theory and Experiment for an Ablating-Capillary Discharge and Application to Electrothermal-Chemical Guns." BRL-TR-3355, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, June 1992.

White, K., I. Stobie, B. Bensinger, S. Driesen, G. Katulka, H. Burden, and A. Juhasz. "Ballistic Diagnostics of Electro-thermal Chemical Propulsion Using a 30-mm Fixture." 28th JANNAF Combustion Meeting, Brooks Air Force Base, San Antonio, TX, CPIA Publication 573, vol. I, pp. 153–164, October 1991.

INTENTIONALLY LEFT BLANK.

No. of Copies	Organization
2	Administrator Defense Technical Info Center ATTN: DTIC-DDA Cameron Station Alexandria, VA 22304-6145
1	Commander U.S. Army Materiel Command ATTN: AMCAM 5001 Eisenhower Ave. Alexandria, VA 22333-0001
1	Director U.S. Army Research Laboratory ATTN: AMSRL-OP-CI-AD, Tech Publishing 2800 Powder Mill Rd. Adelphi, MD 20783-1145
1	Director U.S. Army Research Laboratory ATTN: AMSRL-OP-CI-AD, Records Management 2800 Powder Mill Rd. Adelphi, MD 20783-1145
2	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-IMI-I Picatinny Arsenal, NJ 07806-5000
2	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-TDC Picatinny Arsenal, NJ 07806-5000
1	Director Benet Weapons Laboratory U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-CCB-TL Watervliet, NY 12189-4050
1	Director U.S. Army Advanced Systems Research and Analysis Office (ATCOM) ATTN: AMSAT-R-NR, M/S 219-1 Ames Research Center Moffett Field, CA 94035-1000

No. of Copies	Organization
1	Commander U.S. Army Missile Command ATTN: AMSMI-RD-CS-R (DOC) Redstone Arsenal, AL 35898-5010
1	Commander U.S. Army Tank-Automotive Command ATTN: AMSTA-JSK (Armor Eng. Br.) Warren, MI 48397-5000
1	Director U.S. Army TRADOC Analysis Command ATTN: ATRC-WSR White Sands Missile Range, NM 88002-5502
(Class. only) 1	Commandant U.S. Army Infantry School ATTN: ATSH-CD (Security Mgr.) Fort Benning, GA 31905-5660
(Unclass. only) 1	Commandant U.S. Army Infantry School ATTN: ATSH-WCB-O Fort Benning, GA 31905-5000
1	WL/MNOI Eglin AFB, FL 32542-5000
	Aberdeen Proving Ground
2	Dir, USAMSAA ATTN: AMXSY-D AMXSY-MP, H. Cohen
1	Cdr, USATECOM ATTN: AMSTE-TC
1	Dir, USAERDEC ATTN: SCBRD-RT
1	Cdr, USACBDCOM ATTN: AMSCB-CII
1	Dir, USARL ATTN: AMSRL-SL-I
5	Dir, USARL ATTN: AMSRL-OP-CI-B (Tech Lib)

No. of Copies	Organization
1	OSD/SDIO/IST ATTN: Dr. Len Caveny Pentagon Washington, DC 20301-7100
1	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-QAH-T, Mr. John Domen Building 62 North Picatinny Arsenal, NJ 07806-5000
1	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-AEE-BR, Mr. Ken Klingaman Building 1501 Picatinny Arsenal, NJ 07806-5000
1	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-ASI, Dr. Jerry Rubin Picatinny Arsenal, NJ 07806-5000
1	Director U.S. Army BMD Advanced Technology Center P. O. Box 1500 Huntsville, AL 35807
1	Chairman DOD Explosives Safety Board Room 856-C Hoffman Bldg. 1 2461 Eisenhower Ave. Alexandria, VA 22331-0600
1	Department of the Army Office of the Product Manager 155mm Howitzer, M109A6, Paladin ATTN: SFAE-AR-HIP-IP, Mr. R. De Kleine Picatinny Arsenal, NJ 07806-5000
1	Commander, USACECOM R&D Technical Library ATTN: ASQNC-ELC-IS-L-R, Myer Center Fort Monmouth, NJ 07703-5301

No. of Copies	Organization
1	PEO-Armaments Project Manager Tank Main Armament Systems ATTN: AMCPM-TMA, K. Russell Picatinny Arsenal, NJ 07806-5000
1	PEO-Armaments Project Manager Tank Main Armament Systems ATTN: AMCPM-TMA-105 Picatinny Arsenal, NJ 07806-5000
1	PEO-Armaments Project Manager Tank Main Armament Systems ATTN: AMCPM-TMA-120 Picatinny Arsenal, NJ 07806-5000
1	Commander Production Base Modernization Agency U.S. Army Armament Research, Development, and Engineering Center ATTN: AMSMC-PBM-E, L. Laibson Picatinny Arsenal, NJ 07806-5000
5	Director Benet Laboratories U.S. Army Watervliet Arsenal ATTN: SARWV-RD, G. Carafano R. Thierry R. Hasoenbein P. Votis P. Alto Watervliet, NY 12189
3	Commander U.S. Army AMCCOM ATTN: AMSMC-IRC, G. Cowan SMCAR-ESM(R), W. Fortune R. Zastrow Rock Island, IL 61299-7300
1	Commandant U.S. Army Aviation School ATTN: Aviation Agency Fort Rucker, AL 36360

No. of Copies	Organization
1	Director HQ, TRAC RPD ATTN: ATCD-MA, MAJ Williams Fort Monroe, VA 23651-5143
1	Headquarters U.S. Army Materiel Command ATTN: AMCICP-AD, Michael F. Fisette 5001 Eisenhower Ave. Alexandria, VA 22333-0001
1	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-CCD, D. Spring Picatinny Arsenal, NJ 07806-5000
1	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-CCS Picatinny Arsenal, NJ 07806-5000
1	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-CCH-T, L. Rosendorf Picatinny Arsenal, NJ 07806-5000
1	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-CCH-V, E. Fennell Picatinny Arsenal, NJ 07806-5000
1	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-AE, J. Picard Picatinny Arsenal, NJ 07806-5000
1	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-AEE, J. Lannon Picatinny Arsenal, NJ 07806-5000

No. of Copies	Organization
5	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-AEE-B, A. Beardell D. Downs S. Einstein A. Bracuti D. Chiu Picatinny Arsenal, NJ 07806-5000
1	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-AES, S. Kaplowitz Picatinny Arsenal, NJ 07806-5000
1	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-FSA-T, M. Salsbury Picatinny Arsenal, NJ 07806-5000
6	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-FSE, T. Gora B. Knutelsky K. C. Pan W. Davis C. Durham A. Graf Picatinny Arsenal, NJ 07806-5000
6	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-EG, G. Ferdinand H. Naber-Libby R. Lundberg J. Niles R. Moreira W. Morelli Picatinny Arsenal, NJ 07806-5000

No. of Copies	Organization
3	U.S. Army Research Laboratory Electronics and Power Sources Directorate Pulse Power Center ATTN: AMSRL-EP-MC, Dr. D. Singh Dr. T. Poldesak Mr. R. Pastore Bldg 2707 Fort Monmouth, NJ 07703-5000
2	Commander U.S. Army Research Office ATTN: Technical Library D. Mann P.O. Box 12211 Research Triangle Park, NC 27709-2211
1	Commander U.S. Army Belvoir R&D Center ATTN: STRBE-WC, Technical Library (Vault) Bldg. 315 Fort Belvoir, VA 22060-5606
1	Commander U.S. Army TRAC - Fort Lee Defense Logistics Studies Fort Lee, VA 23801-6140
1	President U.S. Army Artillery Board Fort Sill, OK 73503
1	Commandant U.S. Army Command and General Staff College Fort Leavenworth, KS 66027-5200
1	Commandant U.S. Army Special Warfare School ATTN: Rev and Tng Lit Div Fort Bragg, NC 28307
1	Commander Radford Army Ammunition Plant ATTN: SMCRA-QA/HI Library Radford, VA 24141
1	Commandant U.S. Army Field Artillery School ATTN: STSF-TSM-CN Fort Sill, OK 73503-5600

No. of Copies	Organization
4	Deputy Commander Strategic Defense Command ATTN: SFAE-SD-HVL, S. Smith LTC Kee D. Lianos T. Aden P.O. Box 1500 Huntsville, AL 35887-8801
3	Commander U.S. Army Foreign Science and Technology Center ATTN: AMXST-MC-3, S. LeBeau C. Beiter 220 Seventh St., NE Charlottesville, VA 22901
1	Commandant U.S. Army Field Artillery Center and School ATTN: ATSF-CO-MW, B. Willis Fort Sill, OK 73503
1	Naval Sea System Command Department of the Navy ATTN: CSEA, CDR Dampier 06KR12 Washington, DC 20362-5101
1	Office of Naval Research ATTN: Code 473, R. S. Miller 800 N. Quincy St. Arlington, VA 22217
2	Commander Naval Sea Systems Command ATTN: SEA 62R SEA 64 Washington, DC 20362-5101
1	Commander Naval Air Systems Command ATTN: AIR-954-Technical Library Washington, DC 20360
1	Naval Research Laboratory Technical Library Washington, DC 20375

No. of Copies	Organization
2	Commander Naval Surface Warfare Center ATTN: J. P. Consaga C. Gotzmer Silver Spring, MD 20902-5000
2	Commander Naval Surface Warfare Center ATTN: K. Kim/Code R-13 R. Bernecker/Code R-13 Silver Spring, MD 20902-5000
3	Commander Naval Surface Warfare Center Indian Head Division ATTN: 610, C. Smith 6110J, K. Rice 6110C, S. Peters Indian Head, MD 20640-5035
6	Commanoer Dahlgren Division Naval Surface Warfare Center ATTN: Code G33, T. Doran J. Copley Code G30, Guns and Munitions Division Code G301, D. Wilson Code G32, Guns Systems Division Code E23, Technical Library Dahlgren, VA 22448-5000
1	Commander Naval Surface Weapon Center Indian Head Division ATTN: Code 270P1, Mr. Ed Chan 101 Straus Avenue Indian Head, MD 20640
1	Commander Naval Surface Weapon Center Indian Head Division ATTN: Code 3120, Mr. Robert Rast 101 Straus Avenue Indian Head, MD 20640

No. of Copies	Organization
1	Commander Naval Surface Weapon Center Indian Head Division ATTN: Code 210P1, Mr. Ron Simmons 101 Straus Avenue Indian Head, MD 20640
2	Commander Naval Surface Weapon Center Indian Head Division ATTN: Code 6210, Sharon Boyles Norberto Almeyda 101 Straus Avenue Indian Head, MD 20640
1	Naval Air Warfare Center ATTN: Code 3891, Mr. Chan Price China Lake, CA 93555
1	Commander Naval Air Warfare Center ATTN: Code 3891, Ms. Alice Atwood China Lake, CA 93555
1	Commander Naval Weapons Center ATTN: Code 388, C. F. Price Info Science Div China Lake, CA 93555-6001
1	OLAC PL/TSTL ATTN: D. Shiplett Edwards AFB, CA 93523-5000
10	Central Intelligence Agency Office of Central Reference Dissemination Branch Room GE-47 HQS Washington, DC 20502
1	Central Intelligence Agency ATTN: Joseph E. Backofen HQ Room 5F22 Washington, DC 20505

No. of Copies | Organization

5 Director
Sandia National Laboratories
ATTN: T. Hitchcock
R. Woodfin
D. Benson
S. Kempka
R. Beasley
Advanced Projects Div 14
Organization 9123
Albuquerque, NM 87185

2 Director
Los Alamos National Laboratory
ATTN: B. Kaswhia
H. Davis
Los Alamos, NM 87545

1 Director
Lawrence Livermore National Laboratory
ATTN: M. S. L-355, A. Buckingham
P.O. Box 808
Livermore, CA 94550

2 Director
Sandia National Laboratories
Combustion Research Facility
ATTN: R. Armstrong
S. Vosen
Division 8357
Livermore, CA 94551-0469

1 University of Illinois
Dept. of Mech./Indust. Engr.
ATTN: Professor Herman Krier, 144 MEB
1206 N. Green St.
Urbana, IL 61801

1 The Johns Hopkins University/CPIA
ATTN: T. Christian
10630 Little Patuxent Parkway, Suite 202
Columbia, MD 21044-3200

1 State University of New York
Department of Electrical Engineering
ATTN: Dr. W. J. Sargeant
Bonner Hall - Room 312
Buffalo, NY 14260

No. of Copies | Organization

1 The Johns Hopkins University
Applied Physics Laboratory
Chemical Propulsion Information Agency
John Hopkins Road
Laurel, MD 20707

1 Pennsylvania State University
Propulsion Engineering Research Center
Mechanical Engineering Department
ATTN: Dr. Kenneth K. Kuo
140 Research Building "E"
University Park, PA 16802

1 Texas Technical University
Department of EE/Computer Science
ATTN: Dr. M. Kristiansen
Lubbock, TX 79409-4439

2 University of Delaware
Department of Electrical Engineering
ATTN: Dr. R. Hunsperger
Dr. C. Ih
Newark, DE 19716

1 University of Texas at Arlington
Department of Electrical Engineering
ATTN: Dr. Loyd B. Gordon
Box 19016
Arlington, TX 76019-0016

3 Wilkes University
Department of Electrical Engineering
ATTN: Dr. Ar. Armand,
Chairman EE Department
Dr. Y. Choe
Dr. T. Srinivasan
Wilkes-Barre, PA 18766

2 Pennsylvania State University
Dept. of Mechanical Engr.
ATTN: Jeff Brown
312 Mechanical Engineering Bldg.
University Park, PA 16802

1 North Carolina State University
ATTN: John G. Gilligan
Box 7909
1110 Burlington Engineering Labs
Raleigh, NC 27695-7909

No. of Copies	Organization
2	Institute for Advanced Studies ATTN: Dr. H. Fair Dr. T. Kiehne 4030-2 West Baker Lane Austin, TX 78759-5329
1	SRI International Propulsion Sciences Division ATTN: Technical Library 333 Ravenswood Ave. Menlo Park, CA 94025
1	SPARTA ATTN: Dr. Michael Holland 9455 Towne Center Dr. San Diego, CA 92121-1964
5	FMC Corporation ATTN: Mr. G. Johnson Mr. M. Seale Dr. A. Giovanetti Mr. J. Dyvik Dr. D. Cook 4800 East River Rd. Minneapolis, MN 55421-1498
2	Hercules Inc. Radford Army Ammunition Plant Manager Manufacturing Engineering Department ATTN: D. A. Worrell Edward Sanford P.O. Box 1 Radford, VA 24141
1	Hercules Inc. ATTN: Dr. Richard Cartwright 100 Howard Blvd. Kenvil, NJ 07847
3	GT Devices ATTN: Dr. S. Goldstein Dr. R. J. Greig Dr. N. Winsor 5705A General Washington Dr. Alexandria, VA 22312

No. of Copies	Organization
3	General Dynamics Land Systems ATTN: Dr. B. VanDeusen Mr. F. Lunsford Dr. M. Weidner P.O. Box 2074 Warren, MI 48090-2074
2	Alliant Techsystems, Inc. ATTN: R. E. Tompkins J. Kennedy 7225 Northland Drive Brooklyn Park, MN 55428
4	Olin Ordnance ATTN: V. McDonald, Library Hugh McElroy Mr. Thomas Bourgeois Mr. Dennis Worthington P.O. Box 222 St. Marks, FL 32355
1	Paul Gough Associates, Inc. ATTN: P. S. Gough 1048 South St. Portsmouth, NH 03801-5423
1	Physics International Library ATTN: H. Wayne Wampler P.O. Box 5010 San Leandro, CA 94577-0599
2	Rockwell International Rocketdyne Division ATTN: BA08, J. E. Flanagan J. Gray 6633 Canoga Ave. Canoga Park, CA 91304
2	Princeton Combustion Research Laboratories, Inc. ATTN: M. Summerfield N. Messina Princeton Corporate Plaza 11 Deerpark Drive Bldg. IV, Suite 119 Monmouth Junction, NJ 08852

No. of Copies	Organization
2	Science Applications, Inc. ATTN: J. Batteh L. Thornhill 1519 Johnson Ferry Rd. Suite 300 Marietta, GA 30062-6438
1	Eli Freedman & Associates ATTN: E. Freedman 2411 Diana Rd. Baltimore, MD 21209
1	Rocketdyne ATTN: Mr. Otto Heiney Mail Stop BA26 6633 Canoga Avenue Canoga Park, CA 91304
1	Thiokol (Longhorn Division) ATTN: Dr. David Dillehay Mail Stop 703-11 P.O. Box 1149 Marshall, TX 75671
1	Thiokol (Elkton Division) ATTN: Dr. Rodney Willer 55 Thiokol Road Elkton, MD 21922
1	Veritay Technology, Inc. ATTN: Mr. E. Fisher 4845 Millersport Highway East Amherst, NY 14051-0305
1	Veritay Technology, Inc. 4845 Millersport Hwy. P.O. Box 305 East Amherst, NY 14051-0305
1	Battelle TWSTIAC 505 King Ave. Columbus, OH 43201-2693
2	California Institute of Technology Jet Propulsion Laboratory ATTN: L. D. Strand, MS 125-224 D. Elliot 4800 Oak Grove Dr. Pasadena, CA 91109

No. of Copies	Organization
1	General Electric Co. Defense Systems Division ATTN: Dr. J. Mandzy Mail Drop 43-220 100 Plastics Ave. Pittsfield, MA 01201
2	SAIC ATTN: Mr. N. Sinha Dr. S. Dash 501 Office Center Drive Fort Washington, PA 19034-3211
1	Science Application International Corporation ATTN: Dr. George Chryssamellis 8400 Normandele Blvd. Suite 939 Minneapolis, MN 55437
1	Hercules, Inc. ATTN: Dr. Richard Cartwright 100 Howard Blvd. Kenvil, New Jersey 07847
1	Sandia National Laboratories ATTN: Mr. Mark Grubelich, DIV 2515 P.O. Box 5800 Albuquerque, NM 87185
1	IMI Services USA ATTN: Mr. G. Rashba 2 Wisconsin Circle Suite 420 Chevy Chase, MD 20815
1	Science Applications International Corporation ATTN: Dr. Keith Jamison 1247-B North Eglin Parkway Shalimar, FL 32579
1	Engineering Resources Corp of America ATTN: Mr. R. A. Hill P.O. Box 161 Linthicum, MD 21090

No. of Copies	Organization
	Aberdeen Proving Ground
12	Cdr, USACSTA ATTN: S. Walton G. Rice D. Lacey C. Herud STECS-DA-ID, Mr. Wallace Dr. Francis STECS-AA-AE, Mr. Martin CPT Browning ATTN: STECS-AA-AE, T. Khong (4 cp)
45	Dir, USARL ATTN: AMSRL-WT-P, I. May AMSRL-WT-PA, T. Minor A. Juhasz K. White D. Gordner S. Fortier M. DelGuercio J. Despirito I. Stobie B. Oberle P. Tran G. Wren A. Birk M. McQuaid J. Knapton P. Reeves T. Coffee G. Katulka (10 cp) AMSRL-WT-PE, A. Horst T. Rosenberger J. Colburn A. Williams R. Lieb L. M. Chang P. Conroy B. Raley AMSRL-WT-PD, B. Burns AMSRL-WT-PC, R. Beyer R. Fifer AMSRL-WT-PB, E. Schmidt AMSRL-WT-T, W. Morrison AMSRL-WT-WC, T. Haug

No. of Copies	Organization
	AMSRL-WT-WD, C. Hummer C. Hollandsworth J. Powell A. Zielinski

No. of Copies	Organization
2	RARDE GS2 Division Building R31 ATTN: Dr. C. Woodley Dr. G. Cook Fort Halstead Sevenoaks, Kent TN14 7BP ENGLAND
1	Materials Research Laboratory Salisbury Branch ATTN: Anna Wildegger Gaissmaier Explosives Ordnance Division Salisbury S th Australia 5108
1	Laboratorio Quimico Central de Armamento ATTN: Capitan Juan Francisco Hernandez Tamayo Apartado Oficial 1.105 28080-Madrid-SPAIN
1	R&D Department ATTN: Dr. Pierre Archambault 5 Montee des Arsenaux Le Gardeur, Quebec, Canada J5Z 2P4
1	TZN Forschungs- und Entwicklungszentrum ATTN: Mr. T. Wise, Dr.-Ing. Abt. SE, Fachbereich: Hochleistungspulstechnik Neuensothriether Straße 20 D-3104 Unterlüb, Germany
1	Ernst-Mach-Institute ATTN: Dr. Gustav-Adolph Schröder Hauptstraße 18 D-7858 Weil am Rhein, Germany
2	Institut Franco-Allemand ATTN: Dr. M. Samirant Mr. D. Grune F 68301 SAINT-LOUIS Cédex, 12, rue de l'Industrie, B. P. 301, France

USER EVALUATION SHEET/CHANGE OF ADDRESS

This Laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers to the items/questions below will aid us in our efforts.

1. ARL Report Number ARL-TR-316 Date of Report December 1993

2. Date Report Received ____________________

3. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.) ____________________

4. Specifically, how is the report being used? (Information source, design data, procedure, source of ideas, etc.) ____________________

5. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided, or efficiencies achieved, etc? If so, please elaborate. ____________________

6. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.) ____________________

CURRENT ADDRESS

Organization

Name

Street or P.O. Box No.

City, State, Zip Code

7. If indicating a Change of Address or Address Correction, please provide the Current or Correct address above and the Old or Incorrect address below.

OLD ADDRESS

Organization

Name

Street or P.O. Box No.

City, State, Zip Code

(Remove this sheet, fold as indicated, tape closed, and mail.)

(DO NOT STAPLE)